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BUILDING FERTILITY in EXPOSED SUBSOIL

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OHIO AGRICULTURAL EXPERIMENT STATION

WOOSTER, OHIO

CONTENTS

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The Wooster Experiment was planned by R. M. Salter and worked on successively by R. E. Yoder and C. E. Evans. The assistance of H. L. Borst, Project Supervisor, Agricultural Research Service, U. S. D. A., in interpretation of data and their presentation in this bulletin is gratefully recognized.

BUILDING FERTILITY IN EXPOSED SUBSOIL

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INTRODUCTION

The lowered productivity of soils, caused by erosion, is of wide interest, not only to those engaged in agriculture, but also to the general public. The low fertility of subsoils has long been recognized and considerable evidence is available regarding the reasons for the difference between subsoil and topsoil productivity. Studies were made on this subject in Europe many years ago.

Stallings (12) has summarized much of the data from various states on the relationship between depth of topsoil and yield of crops. Of interest among the papers reviewed in the report is that of Murray, Englehorn and Griffin (9) who set out to determine the productivity of various Iowa soil types. They found that the depth of any particular topsoil influenced production more than the type of soil. They reported a definite tendency for yields to increase with depth of surface soil up to 10 inches. For depths over 10 inches there was no clearly defined relationship between depth and yield.

Conrey and Burrage (3) reported the effects of erosion on the long-time fertility plots at the Ohio Agricultural Experiment Station. Wheat yields were 32 bushels per acre where 5 inches of soil had been lost, 38 bushels where no erosion had occurred and 48 bushels where the eroded topsoil had been deposited to a depth of 14 inches.

Borst, et al. (2) reported yields of unfertilized corn in continuous culture on normally eroded Muskingum silt loam soil and on desurfaced soil or subsoil. The 10-year average yield on the area with normal erosion was 14 bushels per acre; on the subsoil it was a small fraction of a bushel.

Alway and McDole (1) found that semi-arid loess subsoils in Nebraska were very unproductive for non-legumes but that legumes grew on them as well as on the corresponding topsoils. After several

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crops of legumes, corn yielded well on the subsoil. These observations and subsequent experiments indicated that a lack of nitrogen accounted for the unproductiveness of this subsoil.

Gardner (4) of Colorado concluded from greenhouse experiments that subsoil "rawness" was caused by a lack of both phosphorus and nitrogen.

Smith and Pohlman (11), in greenhouse studies with 5 types of associated topsoils and subsoils, concluded that most subsoils are inferior to topsoils even after phosphorus and potassium needs were supplied. Only 2 of the subsoils were improved by manure.

Hays, Bay and Hull (6) worked on an eroded loess soil (Fayette) of northeastern Wisconsin. After 5 years of a rotation including 3 years of alfalfa-bromegrass with lime and fertilizer treatment, corn production on the badly eroded land exceeded that on land with only normal erosion. Small grain production following the corn remained lower on the subsoil.

Latham (7) using three horizons of the Cecil soil series concluded that the subsoil of this series could be greatly improved through the addition of organic matter and an adequate supply of plant nutrients.

Rost (10) working with six different profiles found that the unproductivity of these subsoils was due chiefly to lack of nitrogen and phosphorus. In some instances subsoil productivity was improved by addition of potash.

Harmer (5) reported some Minnesota subsoils produced inoculated legumes as well as the corresponding topsoils while others did not. McMiller (8), in studying these unproductive subsoils, found that they would grow inoculated legumes if supplied with phosphate and potash.

The work cited indicates that subsoils are generally less productive than topsoils. The chief reasons for the low productivity of the subsoils studied were deficiencies in nitrogen, phosphorus and potassium. Subsoils also are known to be unproductive because of high acidity or extremely poor physical condition.

EXPERIMENTAL

The work herein reported involves two soil types; (a) Canfield silt loam located at the Ohio Agricultural Experiment Station, Wooster and (b) Celina silt loam at the Ohio State University, Columbus, Ohio. The subsoil under the former is easily worked; that under the latter is a "problem" subsoil as regards physical condition.

TABLE 1.—Composition of Soils Used in Topsoil vs. Subsoil Comparisons

Depth of Soil	Mechanical Analyses			Nutrients per Acre		
	Sand	Silt	Clay	Total N	Available P	Exchangeable K
In.	Pct.	Pct.	Pct.	Lb.	Lb.	Lb.
	A. VIRGIN CANFIELD SILT LOAM—WOOSTER					
0— 8	18	66	16	2500	44	224
8—16	20	56	24	980	22	190
16—20	23	45	32	900	14	230
	B. CULTIVATED CELINA SILT LOAM—COLUMBUS					
0— 8	21	57	23		37	176
8—16	24	44	32		19	160

The objectives of the work were (a) to compare the productivity of these two topsoils with their respective subsoils and (b) to study subsoil deficiencies and the effects of different rejuvenating treatments on the subsoils. Part 1 of this paper reports the work on the Canfield soil; Part 2, that on the Celina soil.

PART 1. THE CANFIELD SOIL

Canfield silt loam is a gray-brown Podzolic timber soil of the northeastern United States. It is an acid, glaciated soil derived from sandstone and shale. Its internal drainage is fairly good. The friable topsoil (A horizon) is 6 to 8 inches deep. Below this a rather similar subsoil extends for another 18 or 20 inches with gravelly glacial material farther down. Table 1 shows the chemical and physical differences found at various depths when the soil used for this test was examined by 8-inch layers. The least difference is in exchangeable potassium which appears to be quite stable to a depth of 24 inches. All other components show measurable differences. Nitrogen in either layer of subsoil is about two-fifths that of topsoil (also see Table 7). Available phosphorus in the first 8-inch layer of subsoil decreases to one-half of that in the topsoil and to one-third in the second subsoil layer. The content of silt decreased with depth of soil; sand and clay increased.

The site selected for the Wooster experiment was in an area which never had been plowed. The rotting stumps of the original timber had been cleared away only a dozen or so years earlier. Poverty grass (danthonia spicata), briars and other non-economic vegetation covered the soil.

During the summer of 1936 the topsoil, to an average depth of about 7 inches, was mechanically removed from one tract of slightly more than one-half acre. This provided the exposed subsoil area. The removed soil was evenly spread over an adjacent tract of the same general size and thus "double depth topsoil" was produced. A third tract of "single-depth topsoil" was left without change.

Each area was laid out in 11 one-twentieth acre plots, 16 feet wide by 136 feet long, with 2-foot alleys between plots. Different rotations and different treatments were followed on the 11 plots but all 3 sections were treated alike. The restricted area made it impossible to grow each crop every year but corn occupied all the plots every fourth year. For the three intervening years the cropping pattern was set by the particular rotation assigned to any given plot.

Because of the exploratory nature of the experiment this variety of rotations and treatments was considered more important than having each crop each year but with fewer variables. However, yield trends were so definite that a high degree of significance can be attributed to the results obtained.

Treatments, rotations and plot numbering as given below were identical on all 3 sections.

(a) "Fertilizer" means 100 pounds of 0-14-6 on corn and 400 pounds on wheat—a total of 500 pounds per acre every 4 years.

(b) "Manure" means an amount equal to the air-dry weight of crops removed (except wheat grain), including cornstalks and all straw. One-half of this amount was plowed down for corn and one-half applied as top-dressing on wheat.

With this method of determining the amounts of manure, the subsoil, which produced the smallest crops, received the least amount of manure and the high-yielding double-depth topsoil the largest amount. For the first rotation arbitrary amounts of 6 tons were applied on corn and 6 tons on wheat.

Rotation 1: Corn-corn-wheat-mixed hay
Plot 1, No treatment
" 2, Lime to pH 6.5; fertilizer

Rotation 2: Corn-oats-wheat-mixed hay
Plot 3, No treatment
" 4, Lime to pH 6.5
" 5, Lime to pH 6.5, fertilizer
" 6, Lime to pH 6.5, fertilizer, manure

Rotation 3:	Corn-wheat-alfalfa-alfalfa	
	Plot 7,	Lime to pH 7.0; fertilizer
	" 8,	Lime to pH 7.0; fertilizer, manure
Rotation 4:	Corn-oats-alfalfa-wheat (swcl).	
	Plot 9,	Lime to pH 7.0; fertilizer, residues
	" 10,	Lime to pH 7.0; fertilizer, residues removed
Rotation 5:	Corn-wheat-alfalfa-alfalfa	
	Plot 11,	Sweeclover-orchardgrass for green manure the first 4 years, then similar to Plot 7

RESULTS

Data obtained from Plots 1 to 8 contribute some very useful information relative to (1) the value of soil depth and (2) the rejuvenation of unproductive subsoils. Results from Plots 9 to 11 are less valuable because of certain digressions which prevented strict consistency in Rotations 4 and 5 during the first 13 years of the test.

Crop yields obtained in Rotations 1, 2 and 3 are presented in Appendix Tables 17 to 20. More critical comparisons between double-depth and normal-depth topsoil are contained in Table 2. Yield trends on subsoil in comparison with crop behavior on normal-depth topsoil are outlined in Tables 3 to 6.

DOUBLE-DEPTH vs. SINGLE-DEPTH TOPSOIL

The several comparisons of crop yields shown in Table 2 indicate a general superiority of the double-depth topsoil. But they also show that, as improvements were made in soil treatments or in the crop rotation, the yields on single-depth topsoil increased more than they did on the double-depth area. On this latter area corn yields were increased from 106 bushels per acre in Rotation 2 on untreated soil to 124 bushels in Rotation 3 on treated areas. This difference of 18 bushels compares with 43 bushels obtained on single-depth topsoil from the same changes in treatment and rotation.

Without treatment, the average corn yield on the normal topsoil was 61 percent of that on the double-depth area; with treatment, including change of rotation, it increased to 87 percent.

Oats lodged more on the double-depth soil and this tendency was increased by manure applied to previous crops in the rotation. Consequently, larger yields were obtained on the topsoil of normal depth.

Wheat was affected somewhat by lodging, but the average yield relationships were similar to those shown by corn. Without soil treatment, wheat yields in Rotation 2 averaged 71 percent as much on single-depth as on double-depth soil. Treatment increased relative yields to 85 percent. Then with the change to Rotation 3 the relative yields rose to 97 percent. Wheat occurred one year earlier in Rotation 3, so the percentage comparison is more indicative of rotation effects than are the actual yields.

This consistent gain in relative wheat yields on single-depth topsoil apparently bears a relationship to an increasingly better nitrogen supply. On untreated land the poor legume crops could not supply much nitrogen. On treated land the legume growth was better, but even so the wheat appeared the third year after a one-year clover meadow in Rotation 2 (C–O–W–H) when two previous grain crops already had used the greater part of the legume nitrogen. In Rotation 3 (C–W–A–A) the wheat occurred the second year after a two-year alfalfa meadow and thus was one year nearer to a better nitrogen supply.

Hay yields were greatly influenced by the larger nutrient supply in the deeper soil. Without treatment, the yields of first year meadows in Rotation 2 averaged 3.4 and 1.7 tons respectively on double-depth and single-depth soil. Treatment increased the yields to 3.5 and 2.6 tons per acre. Without treatment, the single-depth soil produced only one-half as much hay as the deeper soil but treatment increased the relative amount to about three-fourths. Heavier treatment probably would have produced yields that relatively would have been more favorable to the normal depth soil.

SUBSOIL vs. SINGLE-DEPTH TOPSOIL

The productivity of exposed subsoil was influenced by (a) time, (b) cropping systems and (c) fertility treatments. Because seasons were so variable, the trend in production is best expressed by the percentage relationships that yields on subsoil bear to yields on similarly treated topsoil. This method of comparison reduces to a minimum the effects of seasonal ups and downs and thus simplifies comparison of the data obtained from individual seasons which may be decidedly better or poorer than those 4 years earlier or 4 years later. Percentage yields on subsoil as compared with those on topsoil are given in the right hand columns of Tables 3 to 6. These tables also contain actual yields on the two soils and the loss per acre on subsoil in bushels or tons. Before discussing each crop in detail a few general facts are summarized.

TABLE 2.—Crop Yields on Double-Depth and Single-Depth Topsoil

Items	Yields per Acre (Average of 3 years for each crop)		
	Rotation 2 C-O-W-Cl		Rotation 3 C-W-A-A
	Plot 3 Untreated	Average Plot 5 (LF) Plot 6 (LFM)	Average Plot 7 (LF) Plot 8 (LFM)
	Bu. or T.	Bu. or T.	Bu. or T.
		CORN	
Yield on double-depth soil	106	119	124
Yield on single-depth soil	65	94	108
Extra on double-depth soil	41	25	16
Relative yield on normal soil	61 %	79 %	87 %
		OATS	
Yield on double-depth soil	51	57	——
Yield on single-depth soil	56	61	——
Extra on double-depth soil	—5	—4	——
Relative yield on normal soil	110 %	107 %	——
		WHEAT	
Yield on double-depth soil	31	40	36*
Yield on single-depth soil	22	34	35*
Extra on double-depth soil	9	6	1
Relative yield on normal soil	71 %	85 %	97 %
		FIRST-YEAR MEADOWS	
Yield on double-depth soil	3.4	3.5	3.2*
Yield on single-depth soil	1.7	2.6	2.2*
Extra on double-depth soil	1.7	0.9	1.0
Relative yield on normal soil	50 %	74 %	69 %
		SECOND-YEAR MEADOWS	
Yield on double-depth soil	——	——	3.6
Yield on single-depth soil	——	——	2.9
Extra on double-depth soil	——	——	0.7
Relative yield on normal soil	——	——	81 %

L=Limestone. F=Fertilizer. M=Manure.

*Wheat and first-year meadows occurred one year earlier in Rotation 3 and yields are not directly comparable to those for similar crops in Rotation 2.

Treated topsoil yields were highest; untreated subsoil lowest. This was to be expected from previous knowledge of soil productivity.

Untreated topsoil showed no definite yield trend. The 13 years of the experiment, with good and poor seasons interspersed, represented too short a period for the development of any definite production trend on this untreated virgin topsoil. On Plot 3 in Rotation 2 the yields of the three wheat crops were at about the same mediocre level of 22 bushels per acre. The last two crops of oats each made 50 bushels but these yields were 15 bushels less than that of the first crop. Corn decreased from an initial yield of 77 bushels to 67 to 49 bushels in successive 4-year periods. Then an exceptionally favorable season in 1949 enabled untreated topsoil to produce 80 bushels and thus exceed the first crop 13 years earlier. Meadow yields decreased in each successive 4-year period.

Untreated subsoil shows upward trend except for hay. An upward trend of corn, oats and wheat yields on untreated subsoil was clearly evident. This more or less paralleled the increase in nitrogen content of subsoil shown in Table 18. Hay, however, was decidedly downward from the fairly large yield of 1940. This indicates that perhaps the first crop reduced the available minerals to a low level and recuperative processes did not work sufficiently fast in subsoil to permit meeting or exceeding this early hay yield in later years.

Treated subsoil yields soon rose above those on untreated topsoil. Early in the experiment, yields on untreated topsoil were higher than those on treated subsoil, but before the 13-year period was over the larger yields (with one exception) were harvested on the treated subsoil. The one exception was wheat in the corn-oats-wheat-clover rotation. Reasons for this exception are given in the discussion which centers around Table 5.

CROP TRENDS

Corn. The data in Table 3 show the advantage of the percentage method in charting the comparative trend of subsoil productivity. Because of seasonal conditions, the third corn crop yielded less than the second crop. But the yields on subsoil compared with those on normal soil showed a consistent percentage increase. Also with each passing 4 years the difference between subsoil and topsoil yields became less. Even without treatment the yields on subsoil increased; with treatment they increased more rapidly than those on similarly treated topsoil. For example, on treated Plots 7 and 8 the fourth crop of corn on topsoil yielded 32 bushels more than the first but on subsoil the yield was 72 bushels more. Also with each passing four years the subsoil yields progressively reached a higher percentage of topsoil yields. With treatment the relative yields rose to 89 percent in Rotation 2 and to 84 percent in Rotation 3. The acre yield, however, was higher in Rotation 3.

In the rotation where corn followed a two-year alfalfa sod the last three corn crops on treated subsoil yielded more than the corresponding crops on untreated topsoil. In Rotation 2 where corn followed a one-year mixed meadow, subsoil improvement was less rapid and it was only the last two crops that made larger yields on treated subsoil than on untreated topsoil.

Oats. At Wooster, oats are more sensitive than most crops to the vagaries of weather during the growing season. Consequently, they may not give as reliable indications of soil productivity as the other crops in Rotation 2. But the trends shown in Table 4 are similar to those for corn; viz. (a) actual yields increased on subsoil, (b) the

TABLE 3.—Yield Trends of Corn on Topsoil and Subsoil

Items	Yields by Individual Years				Increase over 1937 yield
	1937	1941	1945	1949	
	Bu.	Bu.	Bu.	Bu.	Bu.
Rotation 2: C-O-W-Cl. Plot 3. No treatment					
Yield on topsoil	77	67	49	80	3
Yield on subsoil	13	31	26	63	50
Loss on subsoil	64	36	23	17	
Relative yield on subsoil	17%	46%	53%	79%	
Rotation 2: C-O-W-Cl. Average Plot 5(LF) and Plot 6(LFM)					
Yield on topsoil	83	96	79	108	25
Yield on subsoil	27	54	60	96	69
Loss on subsoil	56	42	19	12	
Relative yield on subsoil	32%	56%	76%	89%	
Rotation 3: C-W-A-A. Average Plot 7(LF) and Plot 8(LFM)					
Yield on topsoil	84	123	85	116	32
Yield on subsoil	25	81	64	97	72
Loss on subsoil	59	42	21	19	
Relative yield on subsoil	30%	66%	75%	84%	

L=Limestone. F=Fertilizer. M=Manure

difference between topsoil and subsoil yields decreased rapidly and, (c) the relative yield on treated subsoil increased from 16 to 85 prcent of that on treated topsoil. Also like corn, the oats crop on treated subsoil 10 years after desurfacing yielded slightly more than that on untreated topsoil.

Wheat. The seasons in Rotation 2 were one year later than those in Rotation 3 and wheat yields therefore are not directly comparable. But the comparisons (Table 5) of the percentage responses give a good indication why wheat is the only crop in Rotation 2, which failed to yield as much on treated subsoil as on untreated topsoil. More favorable results were obtained in the corn-wheat-alfalfa-alfalfa rotation which permitted sowing wheat on Plots 7 and 8 about five months after plowing the 2-year alfalfa sod for corn. The cornstalks were removed from these plots so the wheat suffered a minimum of competition for the nitrogen which the decaying alfalfa sod continued to supply. Under these conditions wheat responded very similarly to corn and oats. In this more favorable rotation the yields on treated subsoil six and ten years after the desurfacing operation were approximately 80 percent as much as those on treated topsoil.

TABLE 4.—Yield Trends of Oats on Subsoil and Topsoil

Items	Yields by Individual Years			Increase over 1938 yield
	1938	1942	1946	
	Bu.	Bu.	Bu.	Bu.
Rotation 2. C-O-W-Cl. Plot 3. No treatment				
Yield on topsoil	66	50	51	—15
Yield on subsoil	12	18	28	16
Loss on subsoil	54	32	23	
Relative yield on subsoil	19%	35%	56%	
Rotation 2: C-O-W Cl. Average Plot 5(LF) and Plot 6(LFM)				
Yield on topsoil	66	56	61	— 5
Yield on subsoil	11	26	52	41
Loss on subsoil	55	30	9	
Relative yield on subsoil	16%	47%	85%	

L=Limestone. F=Fertilizer. M=Manure.

By contrast, wheat yields on treated subsoil in the corn-oats-wheat-clover rotation remained at 47 percent of those on topsoil. In this rotation the wheat on Plots 5 and 6 was sown about 17 months after plowing the clover sod and after two grain crops already had drawn on the nitrogen supplied by the clover crop. Naturally, the nitrogen left to feed the wheat was less than where only one grain crop grew between the more efficient 2-year alfalfa sod and the wheat.

Meadows. The first meadows grown on subsoil made fairly good yields which were about 80 percent as large as those obtained on similarly treated topsoil. A rotation later, yields tended to be lower on both topsoil and subsoil but the relative yield on subsoil remained at

TABLE 5.—Yield Trends of Wheat on Subsoil and Topsoil

Items	Yields by Individual Years			Increase over 1939 yield
	1939	1943	1947	
	Bu.	Bu.	Bu.	Bu.
Rotation 2: C-O-W-Cl. Plot 3. No treatment				
Yield on topsoil	22	22	21	— 1
Yield on subsoil	2	7	10	8
Loss on subsoil	20	15	11	
Relative yield on subsoil	9%	32%	48%	
Rotation 2: C-O-W-Cl. Average Plot 5(LF) and Plot 6(LFM)				
Yield on topsoil	35	34	34	— 1
Yield on subsoil	10	14	16	6
Loss on subsoil	25	20	18	
Relative yield on subsoil	28%	41%	47%	

Rotation 3: C-W-A-A. Average Plot 7(LF) and Plot 8(LFM)

Items	Yields by Individual Years			Increase over 1938 yield
	1938	1942	1947	
Yield on topsoil	37	28	40	3
Yield on subsoil	9	22	32	23
Loss on subsoil	28	6	8	
Relative yield on subsoil	24%	78%	80%	

L=Limestone. F=Fertilizer. M=Manure.

about 90 percent. But in another 4 years the relative meadow yields on treated subsoil were less than 70 percent as much as on topsoil with similar treatment.

Toward the end of the experiment meadow trends were indicative of decreasing yields per acre and decreasing percentages of topsoil yields. These trends were in sharp contrast to those shown by the grain crops in Tables 3 to 5. Without a single exception the yields of corn,

TABLE 6.—Yield Trends of Meadows on Subsoil and Topsoil

Items	Yields by Individual Years			Increase over 1940 yield
	1940	1944	1948	
	T.	T.	T.	T.
Rotation 2: C-O-W-Cl. Plot 3. No treatment				
Yield on topsoil	2.8	1.3	1.1	—1.7
Yield on subsoil	1.5	0.9	0.4	—1.1
Loss on subsoil	1.3	0.4	0.7	
Relative yield on subsoil	54 %	69 %	36 %	
Rotation 2: C-O-W-Cl. Average Plot 5(LF) and Plot 6(LFM)				
Yield on topsoil	3.4	1.8	2.6	—0.8
Yield on subsoil	2.5	1.6	1.8	—0.7
Loss on subsoil	0.9	0.2	0.8	
Relative yield on subsoil	74 %	89 %	69 %	
Rotation 3: C-W-A-A. Average Plot 7(LF) and Plot 8(LFM)				
Yield on topsoil	4.0	2.3	2.5	—1.5
Yield on subsoil	3.5	2.0	1.6	—1.9
Loss on subsoil	0.5	0.3	0.9	
Relative yield on subsoil	88 %	87 %	64 %	

Items	First-year Meadow			Increase over 1939 yield
	1939	1943	1947	
Yield on topsoil	2.5	3.2	1.1	—1.4
Yield on subsoil	2.1	2.9	1.0	—1.1
Loss on subsoil	0.4	0.3	0.1	
Relative yield on subsoil	84 %	91 %	91 %	

L=Limestone. F=Fertilizer. M=Manure.

oats and wheat on treated subsoil were larger each successive rotation. And without exception they bore a more favorable percentage relationship to the yields obtained on similarly treated topsoil.

Decreases in relative meadow yields probably due to inadequate fertility. The coincidence of meadow decreases in Rotations 2 and 3 occurring in the twelfth year of the experiment might lead to the assumption that the cause of low yields was something that concerned the weather. But because normal hay yields were obtained in other experiments that year it seems logical to conclude that the low yields of hay and decreased percentages on subsoil resulted more from an inadequate fertility program than from unusual weather conditions. (See Discussion Section).

CHANGES IN SOIL NITROGEN CONTENT

Nitrogen varied with soil depth. Spreading approximately 2,800 pounds of nitrogen per acre in 7 inches of topsoil over a similar 7 inches made 14 inches of double-depth soil containing 5,600 pounds of nitrogen per acre. The total was even greater because under these 14 inches was another 900 pounds of nitrogen in the underlying 7 inches of subsoil. The total thus was 6,500 pounds per acre of nitrogen in the double-depth topsoil area compared with 900 pounds in the exposed subsoil area. Nitrogen resources of the double-depth topsoil were about 7 times as large as those in the subsoil area and in single-depth topsoil they were about four times as large. This indicates the severe handicap the subsoil area suffered when crop production was started in 1937. It also explains why lodging of oats and wheat was so much worse on the deepest soil.

Topsoil little changed in nitrogen in 13 years. On the more poorly treated plots the nitrogen content of the topsoil remained about the same during the relatively short 13-year period covered by the analyses in Table 7. On the better treated plots, especially in Rotation 3 with two years of meadow, there was a slight increase in total nitrogen.

Subsoil gained in nitrogen. Exposed subsoil gained in nitrogen content under all conditions throughout the 13 years. The fastest rate of increase occurred during the first 4 years. This varied from 27 percent on poorly treated plots to 47 percent on Plots 7 and 8. Additional increases occurred throughout the 13 years, the greatest of which were made where legume meadows occupied the land for two out of each 4 years. The change in the desurfaced area on Plots 7 and 8 from 940 to 1690 pounds represents an increase of 80 percent in nitrogen. Even with this fairly rapid build-up, the nitrogen content of the subsoil averaged only about half that of the normal soil at the end of the 13 years.

TABLE 7.—Nitrogen per Acre in Seven Inches of Soil in 1937 and at Later Periods

Plots averaged	Rotation	Treatment*	Average 2 plots for 2 consecutive years			
			1937 only Lb.	1940 & 1941 Lb.	1944 & 1945 Lb.	1948 & 1949 Lb.
			A. In Double-depth Soil			
1	C-C-W-H	None	2600	2680	2840	2920
3	C-O-W-H	None				
2	C-C-W-H	LF	2900	2800	2880	3000
4	C-O-W-H	L				
5 & 6	C-O-W-H	LF & LFM	2940	2990	3150	3050
7 & 8	C-W-H-H	LF & LFM	3050	2940	3250	3270
			B. In Single-depth Soil			
1	C-C-W-H	None	3030	2920	2950	2870
3	C-O-W-H	None				
2	C-C-W-H	LF	2840	2940	2890	2860
4	C-O-W-H	L				
5 & 6	C-O-W-H	LF & LFM	2830	2880	2880	2950
7 & 8	C-W-H-H	LF & LFM	2810	3110	3160	3240
			C. In Subsoil Exposed in 1936			
1	C-C-W-H	None	880	1120	1200	1250
3	C-O-W-H	None				
2	C-C-W-H	LF	890	1070	1190	1440
4	C-O-W-H	L				
5 & 6	C-O-W-H	LF & LFM	900	1200	1320	1550
7 & 8	C-W-H-H	LF & LFM	940	1380	1510	1690

*L=Limestone. F=Fertilizer. M=Manure.

BULK DENSITY OF SOILS AFTER 14 YEARS

In September 1949, after the fourth corn crop had been grown and 14 years after the desurfacing of the subsoil area, soil samples were taken for the determination of bulk density. Also sampled was the nearby virgin area which had continued throughout the 14 years with its original cover of poverty grass and other non-economic vegetation.

The data (Table 8) show that soil bulk density was not significantly influenced by cropping during the relatively short period of this experiment. For example, the 8 to 10-inch depth in the virgin area represents the soil layer which became the exposed subsoil. Bulk density values in the virgin subsoil and exposed subsoil were practically the same after 13 years of cropping the latter.

TABLE 8.—Bulk Density of Soils, September, 1949

	Management During the 13 Years		
	4-year rotations		Virgin area covered with poverty grass and weeds
	(1) C-C-W-H Av., Plots 1 & 2	(3) C-W-A-A Av., Plots 7 & 8	
Double-depth topsoil—			
0– 6 inches	1.19	1.18	
8–10 inches	1.26	1.25	
Single-depth topsoil—			
0– 6 inches	1.19	1.14	1.17
8–10 inches	1.39	1.41	1.39
Exposed subsoil—			
0– 6 inches	1.36	1.37	
8–10 inches	1.41	1.46	

SOIL AGGREGATION

Samples for the determination of aggregation were taken in the fall of 1953. It was thought that these determinations would aid in evaluating the status of the desurfaced area after nearly two decades of cropping. Some determinations are given in Table 9. It is of interest that the desurfaced soil which had been in the rotation with two years of meadow (C–W–A–A) showed a small improvement in aggregation

TABLE 9.—Water-Stable Aggregates Over 0.25 mm

	Percent by Weight
Topsoil, virgin, never cropped	57
Subsoil, virgin, never cropped	28
Topsoil, in Rotation 3 (C-W-A-A) sampled in second alfalfa year	51
Desurfaced area, Rotation 3 (C-W-A-A) sampled in second alfalfa year	33
Topsoil, in Rotation 2 (C-O-W-H) sampled after wheat crop	37
Desurfaced area, Rotation 2 (C-O-W-H) sampled after wheat crop	28

over that of the virgin subsoil. In Rotation 2 (C–O–W–H) the desurfaced soil was identical in aggregates over 0.25 mm. with the original subsoil.

The Rotation 3 samples were taken in second year alfalfa, whereas those for Rotation 2 were taken at the end of the wheat year. Very probably the time of sampling (place in rotation) influenced the findings. It appears that there was only slight improvement in the desurfaced soil as regards the qualities which make for soil aggregation.

MEADOW vs. SWEETCLOVER GREEN MANURE

Earlier in this discussion it was stated that Plots 9, 10 and 11 were used in various ways and as a result they did not furnish any great amount of usable data. But they do present one valuable lesson for those who contemplate starting a soil improvement program. For the first 4 years Plot 11 was devoted to growing sweetclover merely for soil improvement. Orchardgrass was added to the sweetclover to increase the amount of organic matter that might quickly be added to the soil. Reseeding offered problems and the soil improvement crop was not always as good as it should have been. However, this probably was a normal experience for anyone who might use the same procedure.

Useful meadows were superior. After four years of sweetclover-orchardgrass the plot was planted to corn along with all other plots in the experiment. In spite of the special efforts that had been made over a four-year period to build up the subsoil the yield of corn as shown in Table 10, was less than it was on Plots 7 and 8 where corn followed two years of alfalfa. Furthermore, Plot 11 returned no income during these four years, whereas Plots 7 and 8 produced valuable crops of alfalfa during the two years previous to growing the corn.

TABLE 10.—Useful Meadows vs. Unharvested Sweetclover-Orchardgrass

Year	Crop		Yield per Acre on Subsoil	
			Average Plots 7 & 8	Single Plot 11
1937	Corn,	Bu.	25	Sweetclover-
1938	Wheat,	Bu.	9	orchardgrass
1939	Alfalfa,	T.	2.1	without
1940	Alfalfa,	T.	3.5	any harvests
1941	Corn,	Bu.	81	47

PHASE II, WOOSTER

Starting with the harvests of 1952, crop yields reflect the results obtained from fertility treatments that were much more liberal than those followed during the first 13 years of the test. With the revised plan the cornstalks remained on the soil. Other crops were removed and (except for wheat grain) returned in manure. Fertilizers were applied quite liberally. The combination of manure and fertilizer carried an average of approximately 55 pounds of phosphoric acid and 65 pounds of potash per acre per year of rotation. On Plot 1 where the meadow was designed to remain for several years the annual application was 500 pounds of 0-20-20 per acre. This carried more phosphoric acid and potash than the rotation treatments but the difference was deemed desirable because of the greater demand of high yielding long-lay meadows. Treatments also provided a nitrogen differential, whereby the grain crops were grown on topsoil and subsoil both with and without applied nitrogen. The amounts, where applied, were 60 pounds per acre for corn and 40 pounds for oats and wheat.

During this relatively short 4-year period the hay yields on the liberally treated subsoil averaged 96 percent as high as on similarly treated topsoil. Moreover, with liberal treatments, meadow yields on subsoil showed about the same pattern as on topsoil. Second-year meadows averaged nearly a third more than first-year meadows and the long-lay meadows about one-half more.

Grain yields during these years were influenced by the larger nitrogen supply resulting from better meadow yields and on certain plots by the nitrogen applied in commercial form. The data in Table 11 show that increases from commercial nitrogen in these rotations with excellent meadow yields barely paid for the nitrogen itself. A comparison of great interest is between subsoil with commercial nitrogen versus topsoil without it. Under these conditions the yields on nitrogen

TABLE 11.—Comparative Crop Yields in Phase II

	Yield of Crops per Acre—4-year Average					
	Corn*	Oats	Wheat*	1st year* meadow	2nd year meadow	Long-lay meadow
A. No Commercial Nitrogen on Subsoil or Topsoil						
Topsoil, Bu. or T.	85	76	40	3.6	4.7	5.2
Subsoil, Bu. or T.	81	61	33	3.5	4.3	5.1
Subsoil, Pct.	95	80	83	97	91	98
B. Commercial Nitrogen on Both Subsoil and Topsoil						
Topsoil, Bu.	93	80	40	—	—	—
Subsoil, Bu.	82	72	37	—	—	—
Subsoil, Pct.	88	90	93	—	—	—
C. Commercial Nitrogen on Subsoil vs. None on Topsoil						
Topsoil, Bu.	85	76	40	—	—	—
Subsoil, Bu.	82	72	37	—	—	—
Subsoil, Pct.	96	95	93	—	—	—

*Average, Rotations 2 and 3.

treated subsoil were corn 96 percent, oats 95 percent and wheat 93 percent as much as they were on topsoil without commercial nitrogen. Factors other than nitrogen undoubtedly tended to keep yields on subsoil below those on topsoil.

PART 2. THE CELINA SOIL, COLUMBUS[4]

A year after the desurfaced soil test was started at Wooster a similar, but much smaller test[4] was started at Columbus on Celina silt loam. Two basic differences were involved, however. First, the location was on soil that had been cropped for an unknown number of years instead of on uncropped virgin soil as at Wooster. Second, the subsoil (Table 1) contained a higher proportion of clay than that at Wooster and this made physical condition in the desurfaced area more of a problem.

The area at Columbus was less than a third as large as that at Wooster so the number of plots was limited to 4 on double-depth soil,

[4]The Columbus experiment was planned by L. D. Baver and worked on successively by B. T. Shaw, J. B. Page and G. S. Taylor.

4 on single-depth soil and 4 on the desurfaced subsoil. Plots were numbered consecutively from north to south and four rotations of four years each were established with only one crop of each rotation occurring in any one year. Plot numbering and rotations were as follows:

Plots 1, 5, 9.	Corn-oats-hay-wheat (swcl).	Fertilizer and manure
Plots 2, 6, 10.	Corn-oats-wheat-hay.	Fertilizer and manure
Plots 3, 7, 11.	Corn-oats-wheat-hay.	No fertilizer or manure
Plots 4, 8, 12.	Corn-wheat-alfalfa-alfalfa.	Fertilizer and manure

The term "hay" means an alfalfa-clover-timothy mixture; "fertilizer" means 500 pounds of 0-14-6 per acre per rotation, and "manure" equals dry weight of crops removed (except wheat grain), applied one-half to corn and one-half to wheat.

Corn yields are listed by years in Table 12. The 1942 crop is not included because of pheasant damage. Three years later corn was grown again because of meadow seeding failures. This was a year earlier than specified in the regular rotation sequences. This loss of soil building sod crops in the various rotations was followed by the lowest corn yields of the 3 crop years reported. For these 3 crop years relative corn yields were 132, 100 and 54 percent respectively on double-depth, single-depth and desurfaced soil.

All corn plots were planted uniformly but stand counts in 1953 varied from 17,800 on double-depth topsoil and 14,500 on single-depth soil to only 8,000 stalks on the desurfaced area. This indicates greater difficulty either in getting corn to germinate on the subsoil area or for the young plants to survive. When all plots were prepared at the same time the heavy character of the exposed subsoil favored a more cloddy seedbed for corn than was the case with the topsoil.

Small grains also suffered bird damage in certain years which were omitted in determining the average yields in Table 13. The size of these yields on the single-depth topsoil indicates a very mediocre level of residual soil fertility or mediocre soil treatment. Judged by present standards there probably was a combination of the two. Corn with 54 percent and wheat with 60 percent, yielded only slightly more than one-half as much on subsoil as on topsoil.

Hay yields in the Columbus test, considered alone, perhaps would not cause any particular comment. But when viewed in connection with trends at Wooster a certain similarity seems to exist. Just as at Wooster alfalfa was the crop that grew most successfully on the desurfaced area. The largest yield was obtained early in the test when 3.5

TABLE 12.—Corn Yields, Ohio State University Desurfacing Experiment

Plot	Rotation (not followed exactly)	Yield, Corn per Acre			
		1945	1949	1953	Av.
		Bu.	Bu.	Bu.	Bu.
	Single-depth Topsoil				
1	C-O-H-W (swcl)	48	83	62	64
2	C-O-W-H	45	71	54	57
3	C-O-W-H, unfertilized	41	64	45	50
4	C-W-H-H	38	67	44	50
	Aveage	43	71	51	55
	Desurfaced Soil				
5	C-O-H-W (swcl)	20	45	24	30
6	C-O-W-H	11	42	25	26
7	C-O-W-H, unfertilized	16	50	20	29
8	C-W-H-H	26	46	34	35
	Average	18	46	26	30
	Double-depth Topsoil				
9	C-O-H-W (swcl)	65	74	62	67*
10	C-O-W-H	69	78	75	74
11	C-O-W-H, unfertilized	59	85	73	72
12	C-W-H-H	74	89	74	79
	Average	67	81	71	73

*This plot was definitely inferior to the others independent of treatment.

tons of hay per acre were harvested from topsoil in 1941 and 2.8 tons from the subsoil. Later yields lowered the average to 2.1 tons on subsoil, but the ratio to topsoil yields remained at the fairly high average of 78 percent. Inasmuch as the subsoil was low in available phosphorus it seems reasonable to assume that heavier phosphate-potash treatments would have favored larger and more profitable hay yields in the later years of the experiment.

The smaller degree of success in building productivity into Celina subsoil than in Canfield subsoil emphasizes that the rate and degree of success in building up desurfaced subsoil depends largely on the nature of the subsoil. The discouraging results obtained on the Celina subsoil corroborate earlier experiences on the University Farm where considerable areas of similar subsoil had been uncovered in certain land levelling

TABLE 13.—Yields and Percentage Relationships on Three Soils at Columbus. Average 3 Years Each Crop

Soil depth	Yields per Acre							
	Corn		Wheat		Oats		Hay	
	Bu.	Pct.	Bu.	Pct.	Bu.	Pct.	T.	Pct.
Single-depth	55	100	25	100	29	100	2.7	100
Desurfaced	30	54	15	60	22	76	2.1	78
Double-depth	73	133	27	108	31	107	2.4	89

operations. Even though these exposed areas have been cropped for 30 years, largely to alfalfa and sweetclover, the original subsoil properties have been only slightly modified. Yields have been improved but the subsoil still is "mean" to work, and obviously still is subsoil.

DISCUSSION

Soil not remade in two decades. Twenty years after the subsoil at Wooster was exposed, its color still was noticeably lighter than that of the topsoil which had been treated in a similar manner. Also, drouth affected crop appearance more quickly on subsoil than on topsoil. These observations added to such criteria as nitrogen content (Table 7) and soil aggregation data (Table 9) indicate that the actual rebuilding of subsoil or badly eroded topsoil is a slow process. Fortunately good crop production did not have to wait for complete soil rebuilding.

Table 14 shows that the penalty for the mechanical removal of topsoil at Wooster varied from a high of $31 per acre per year for the 2 to 5-year subsequent period down to $7 for the 16 to 19-year period. The total penalty for the 18 years (1937 not included) was $252 or more than enough to pay the original cost of the land.

Similar conditions might occur where subsoil is uncovered in land levelling operations, but in ordinary farm practice the loss would be less because topsoil never is completely removed in one season as it was in this test. Measurements taken on the old fertility plots which were laid out on gently rolling land in 1894 indicated that 6 or 7 inches of topsoil were eroded away during the 50 years they were kept in the test. They were cropped in a 5-year rotation of corn, oats, wheat, clover, timothy. Equally large losses can occur in a fraction of that time on steeper slopes when poor crop sequences favor losses from water erosion.

TABLE 14.—Crop Yields per Acre by 4-year Periods. Wooster Rotation 3: Corn, Wheat, Alfalfa, Alfalfa

Crop		1938–1941		1942–1946		1947–1949		1952–1955	
		Top-soil	Sub-soil	Top-soil	Sub-soil	Top-soil	Sub-soil	Top-soil	Sub-soil
Wheat,	Bu.	37.0	9.0	28.0	22.0	40.0	32.0	40.0	34.0
Hay(1),	T.	2.5	2.1	3.2	2.9	1.1	1.0	3.7	3.8
Hay(2),	T.	4.0	3.5	2.3	2.0	2.5	1.6	4.7	4.3
Corn,	Bu.	123.0	81.0	85.0	64.0	116.0	97.0	87.0	80.0
Value per rotation		$340	$217	$258	$211	$277	$221	$347	$321
Loss per rotation			$123		$ 47		$ 56		$ 26
Loss per year			$ 31		$ 12		$ 14		$ 7

Note: 1937 corn crop (not used in computation) yielded 84 bushels on topsoil and 25 bushels on subsoil.

Values: Corn, $1.25 and wheat, $1.75 per bushel; hay, $20 per ton.

Nature helped at Wooster. Soil erosion, fertility depletion and soil building all have been in operation during the nearly two decades since the subsoil was exposed at Wooster. On this friable virgin subsoil the rejuvenating processes greatly overbalanced the evils of current erosion and fertility depletion. Before discussing some specific man controlled factors in rebuilding of this subsoil, attention should be called to untreated Plot 3 where rather large increases in corn, oats and wheat yields (Tables 3-5) and the increase in soil nitrogen (Table 7) were independent of manure and fertilizer applications. Nature apparently was very cooperative on the friable virgin subsoil at Wooster. The untreated "problem" subsoil at Columbus which was under a topsoil with a long cropping history did not show a similar increase in productivity after being brought under cultivation.

VALUE OF MANURE AND FERTILIZERS ON DESURFACED SOIL

Phosphate-potash fertilizer. Table 15 illustrates the effect of fertilizer on subsoil productivity as compared with the same phosphate-potash mixture applied on double-depth and normal-depth topsoil in the corn, oats, wheat, hay rotation at Wooster. The 500 pounds of 0-14-6 per acre every 4 years were divided 100 pounds in the row for corn and 400 pounds on wheat. The effects on corn and oats were fairly comparable on the three soils, but on wheat and the mixed hay they were quite different. Wheat showed a much lower return from phosphate-potash mixtures on subsoil than on topsoil or double-depth soil. The low return from wheat on subsoil probably was due to a deficiency of nitrogen which was at least partly responsible for holding the total yield of wheat on subsoil to less than one-half the yield obtained on topsoil. With nitrogen as the limiting factor, the phosphate-potash fertilizer could not have its full effect on wheat.

TABLE 15.—Comparison of Fertilizer Effects on Subsoil and Topsoil. Wooster

Rotation: Corn, Oats, Wheat, Mixed Hay
Basic treatment: 500 pounds 0-14-6 per acre per rotation

Crop	Increases per Acre; Average of 3 Years, Each Crop		
	Double-depth topsoil	Normal topsoil	Subsoil
Corn, Bu.	13	18	19
Oats, Bu.	17	2	8
Wheat, Bu.	16	16	4
Mixed hay T.	0.4	0.5	1.0
Value per rotation	$64.15	$61.90	$56.35

Values: Corn, $1.25; Oats, $0.70; Wheat, $1.75 per bushel; Hay, $20 per ton.

Because inoculated legumes are independent of soil nitrogen, the effect on meadows of phosphate-potash fertilizer was the opposite of that on wheat. The largest increase in meadow yields was obtained on subsoil where residual plant food was lowest; increases were least on double-depth topsoil where residual levels were highest.

Manure. In Rotation 2, the total amount of manure divided between corn and wheat on subsoil was only 7 tons per acre. As would be expected the 7 tons produced smaller crop increases than the 12 tons applied to normal topsoil. But the value of increases per ton of manure, as shown in Table 16 was greater on the subsoil. In Rotation 3, with two meadow years, the total value of increases and the ton value of manure, both were larger on subsoil.

TABLE 16.—Manure Was More Valuable on Subsoil Than on Topsoil. Wooster

Manure: One-half plowed down for corn and one-half topdressed on wheat

On land fertilized with 500 pounds 0-14-6 per acre per rotation

Rotation (read down)	Increases per Acre; Average of 3 Years, Each Crop		
	Double-depth topsoil	Normal topsoil	Subsoil
Corn, Bu.	14	14	9
Oats, Bu.	—13	2	4
Wheat, Bu.	0	2	2
Mixed hay T.	0	0.6	0.2
Value per rotation	$8.40	$34.40	$21.55
Manure applied	14 T.	12 T.	7 T.
Value per ton of manure	$ 0.60	$ 2.87	$ 3.08
Corn, Bu.	3	4	6
Wheat, Bu.	1	3	10
Alfalfa, T.	1	0.7	0.7
Alfalfa, T.	0.5	0.6	0.3
Value per rotation	$35.55	$37.00	$47.50
Manure applied	15 T.	13 T.	10 T.
Value per ton of manure	$ 2.37	$ 2.85	$ 4.75

Values: Same as in Table 15.

Fertility program was inadequate. The fertility program returned an average of only 18 pounds of phosphoric acid per acre per year on the plots receiving fertilizer alone and 6 or 8 pounds more on those which received manure in addition to fertilizer. This was very inadequate treatment, especially for the subsoil which contained less available phosphorus than the topsoil. Table 1 shows only one-half as much available phosphorus in the subsoil as in the topsoil at the start of this experiment. The analyses given are for soil samples taken in November 1953, but they probably represent conditions 16 years earlier as the area from which the samples were taken had been unplowed, unfertilized and uncropped during that period.

Potash treatments also were inadequate, especially for Rotation 3 where two years of meadow were involved. On the unmanured plots the potash return averaged only 8 pounds per acre per year. Manure applied to the subsoil averaged 7 tons per acre for each 4-year rotation on Plot 6 and 10 tons on Plot 8. If manure is credited with 10 pounds of potash per ton the combined manure and fertilizer treatments carried an average of 25 pounds of potash per acre per year in the corn, oats, wheat, mixed hay rotation and 32 pounds in the corn, wheat, alfalfa, alfalfa rotation. These amounts refer to subsoil treatments; those on topsoil were slightly larger because more manure could be produced from the larger crops grown on topsoil.

Another experiment involving 2 years of meadow (like Rotation 3) was started at Wooster about the same time as the subsoil rejuvenation test. This supplemental experiment soon gave evidence that fertility treatments which carried as little as 30 pounds of potash per acre per year (in addition to the amount in cornstalks) did not sustain high meadow yields. Moreover, as potash deficiency developed, it affected the second-year meadows more quickly than it did the oats and wheat. Depressing effects on corn also were noticeable. Thus, there is considerable logic in attributing the decreased percentage yields of meadows on subsoil (Table 6) to an inadequate fertility system under which the subsoil was depleted of necessary crop nutrients more rapidly than the topsoil. The greater decrease occurred in Rotation 3 where two meadow years drew more minerals from the subsoil than did the one meadow and one oats year in Rotation 2.

Liberal fertilization increased meadow yields. The thesis that these twelfth year percentage decreases in meadow yields on subsoil were due to depletion of necessary nutrients is supported by the early results in Phase 2 of the Wooster experiment. In 1951 the treatments were changed to provide an annual average of 55 pounds of phosphoric acid and 65 pounds of potash per acre on both topsoil and subsoil. This very liberal fertilization was intended to supply adequate nutrients for current needs and also provide some residual amounts. Since the change to this heavier fertilization the hay yields on subsoil have averaged 4.3 tons per acre as compared to 4.5 tons on similarly treated topsoil. With adequate treatment, the subsoil produced 96 percent (Table 11) as much hay as the topsoil. This fact gives strong support to the assumption that the disappointing meadow yields on subsoil during the earlier years of the experiment were due to an inadequate fertility system.

CORN vs. MEADOWS

The **first** corn crop grown on the raw subsoil at both Wooster and Columbus had 6 tons of manure plowed down and 100 pounds of 0-14-6 per acre in the row. No commercial nitrogen was applied. At each place the resulting corn crop had a lower cash value than the meadow which followed it 2 or 3 years later.

Later corn crops on the friable subsoil at Wooster had higher values than the preceding meadows during the first 13 years of the experiment. But under the more liberal soil treatment of Phase 2 the meadow yields were as valuable as corn yields or possibly even more valuable. During this latter period the first-year meadows were lowest, second-year meadows, intermediate and longer-laying meadows highest in yield. The proper value comparisons (Table 11) thus are between 81 bushels of corn and 4.3 tons of hay from second-year meadows or 5.1 tons from meadows kept 4 years.

Cropping results on the "problem" subsoil at Columbus were much less favorable than they were on the friable subsoil at Wooster. Meadow stands were more uncertain and at one point in the test seeding failures made it necessary to plant corn a year ahead of schedule without benefit of a previous sod. Failure to obtain excellent sods to plow under each rotation and some inferior stands of corn on unfavorable seedbeds kept the yields and acre values of corn at low figures. On the average the 30 bushels of corn probably were less profitable than the average meadow yield of 2.1 tons hay (Table 13). Alfalfa was considered the most promising crop on subsoil but no measure of yield under heavy fertilization was made as was done at Wooster.

Corn is the controversial crop in areas where soil erosion is likely to be serious, or where an effort is being made to rebuild eroded and depleted areas. It is the crop which, because of its clean cultivation is likely to permit soil erosion and to decrease soil organic matter. However, the high acre value of high yielding corn and its importance as a high energy feed for all classes of livestock combine to make the crop a desirable one to grow. Furthermore, it is a crop that can be used to capitalize on the nitrogen left in the roots or passed into the manure after harvesting leguminous meadow crops.

Results of the two experiments in Ohio show that corn can be more freely grown on friable subsoils than on subsoils with serious problems of physical condition. From both an economic and a soil management viewpoint it is desirable to precede the corn crop with good meadows or pastures. But if corn is grown before good sods are available, the yield very likely can be increased by intelligent use of commercial nitrogen. Such use of nitrogen is more logical on friable subsoils than on "problem" subsoils where the stand of corn may be poor.

The results, especially at Wooster, encourage the idea that rejuvenation treatments on eroded or badly depleted topsoil may be economically sound, especially where the first cost of the land is low. But the profit, very likely, will be less than that obtained from farming more productive topsoil. The handicap of the eroded or depleted area is its low basal productivity which must be improved to a degree that permits crop yields that are fairly comparable to those obtained on undepleted competitive areas. Liberal treatments at the very start return much quicker and more profitable results although they require larger outlays when income is at its lowest. And at the very start surer reliance can be placed on meadows and pastures than on grain to provide satisfactory returns on the sizable investments in rejuvenation treatments.

SUMMARY PART 1, WOOSTER

Trends in crop yields on double-depth, single-depth (normal) and desurfaced Canfield silt loam were studied during the 13-year period, 1937-1949. Three rotations: (1) corn, corn, wheat, hay, (2) corn, oats, wheat, hay and (3) corn, wheat, alfalfa, alfalfa were grown with and without treatments of limestone, fertilizer and manure.

The subsoil under virgin Canfield silt loam is lower in silt but higher in sand and clay, particularly the latter, than the overlying topsoil; the subsoil is lower in total nitrogen and available phosphorus but about the same in exchangeable potassium.

In 1937, the first year of the experiment, corn yields were lower on the artificially doubled soil because of greater insect injury. During subsequent years for crops in Rotation 2 the untreated single-depth soil produced only 61 percent as much corn, 71 percent as much wheat and 50 percent as much hay as the untreated double-depth soil with its greater reservoir of plant nutrients. Oats yields were reduced each year on the deeper soil because of greater lodging.

On treated soil in the better soil building Rotation 3 the relative yields on single-depth soil increased to 87 percent as much corn, 97 percent as much wheat and 74 percent as much hay as on the double-depth soil.

Grown without applied nitrogen, grain yields were very poor on subsoil the first three years after desurfacing. They increased during each successive 4-year period. Even on untreated Plot 3 in Rotation 2 corn production on subsoil increased from 13 bushels the first rotation to 63 bushels the last rotation; oats from 12 to 28 bushels and wheat from 2 to 10 bushels.

With limestone, fertilizer and manure treatments the yield of corn on subsoil increased to 97 bushels and wheat to 32 bushels per acre in Rotation 3. These latter yields represent 84 and 80 percent, respectively, of the yields obtained on similarly treated topsoil.

During the first 4 years of Phase II (1952-1955) when applied nitrogen was a differential on both soils, the subsoil with commercial nitrogen produced about 95 percent as much grain as the topsoil without it.

In striking contrast to increasing grain yields, after low initial yields, meadow yields started high and declined each successive 4-year period on both subsoil and topsoil. Treatment made larger yields but did not prevent later crops from yielding less than the early ones. These decreases were attributed to inadequate fertility programs.

With the more adequate fertility programs instituted for Phase II of the experiment, hay yields were about as high on subsoil as on topsoil.

Regardless of treatment there was a continued increase in nitrogen content of subsoil during the 13 years of the experiment. The greatest rate of increase was during the first four years after removal of topsoil. Starting with about one-third as much nitrogen as in the topsoil, the better treated plots contained slightly more than one-half as much as in topsoil at the end of 13 years.

Even with good treatment, the bulk density of subsoil remained practically unchanged during the 13-year period.

Soil aggregation after 16 years of cropping still was markedly inferior in the subsoil as compared with similarly treated topsoil.

Crop production on subsoil was rapidly improved by proper treatment but such criteria as nitrogen content, soil color and drouth resistance indicate that the actual rebuilding of topsoil was far from complete at the end of two decades.

Devoting the first four years to growing green manure legume-grass mixtures on subsoil merely for plowing under was not an economic practice; more profitable and longer lasting results were obtained by including in the rotation two years of alfalfa-grass meadows which were valuable for feed as well as soil improvement.

Meadows had the highest cash values of all crops on subsoil during the first rotation but thereafter corn was ahead by a wide margin.

Phosphate-potash fertilizers were about as effective on subsoil as on topsoil. Manure was as valuable or even more valuable on subsoil than on topsoil. It was more valuable per rotation and per ton in Rotation 3 with two years of meadow than in Rotation 2 with 3 years of grain.

PART 2, COLUMBUS

The subsoil under Celina silt loam had less silt and more clay than the Canfield subsoil reported in Part 1. This increased the difficulty of obtaining satisfactory tilth.

The area of Celina silt loam which was used in the test was not virgin land as was the case with the Canfield silt loam at Wooster. Rather, the soil at Columbus had been under cultivation for many years. Crop yields indicated that the fertility level was very mediocre.

Grain yields on topsoil were discouragingly low but, compared with even these low yields, corn production on subsoil was only 54, wheat 60 and oats 76 percent as high as on single-depth topsoil.

Hay yields averaged 2.1 tons per acre on subsoil or 78 percent as much as on topsoil. Alfalfa did the best of any crop on subsoil. It was not tested under heavy fertility treatments.

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Appendix Table 17.—The Influence of Soil Depth on Yield of Corn

Plot	Rotation	Treatment	Yield per Acre			Yield per Acre		
			Double depth	Normal depth	Subsoil	Double depth	Normal depth	Subsoil
			Bu.	Bu.	Bu.	Bu.	Bu.	Bu.
				1937* CORN			1941 CORN	
1	C-C-W-MxH	None	66	73	15	104	64	32
2	C-C-W-MxH	LF	84	84	22	128	94	45
3	C-O-W-MxH	None	72	77	13	113	67	31
4	C-O-W-MxH	L	64	74	11	112	64	28
5	C-O-W-MxH	LF	79	83	22	119	83	44
6	C-O-W-MxH	LFM	78	83	32	137	108	64
	Average, Plots 5 and 6		79	83	27	128	96	54
7	C-W-Al-Al	LF	71	81	24	134	121	76
8	C-W-Al-Al	LFM	71	86	26	141	125	86
	Average, Plots 7 and 8		71	84	25	138	123	81
				1945 CORN			1949 CORN	
1	C-C-W-MxH	None	73	43	22	93	65	51
2	C-C-W-MxH	LF	104	76	49	121	99	77
3	C-O-W-MxH	None	86	49	26	118	80	63
4	C-O-W-MxH	L	77	50	38	109	84	71
5	C-O-W-MxH	LF	96	75	58	121	102	94
6	C-O-W-MxH	LFM	108	83	62	132	113	97
	Average, Plots 5 and 6		102	79	60	127	108	96
7	C-W-Al-Al	LF	102	84	63	130	112	93
8	C-W-Al-Al	LFM	108	86	64	126	120	100
	Average, Plots 7 and 8		105	85	64	128	116	97

*1937 corn crop on double-depth soil severely affected by soil insects.
L=Limestone. F=Fertilizer. M=Manure.

Appendix Table 18.—The Influence of Soil Depth on Second-year Corn, Oats and Wheat Following Corn

Plot	Rotation	Treatment	Yield per Acre			Yield per Acre			Yield per Acre		
			Double depth	Normal depth	Subsoil	Double depth	Normal depth	Subsoil	Double depth	Normal depth	Subsoil
			Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.
			1938			1942			1946		
			SECOND YEAR CORN			SECOND YEAR CORN			SECOND YEAR CORN		
1	C-C-W-MxH	None	88	70	16	80	47	13	55	26	8
2	C-C-W-MxH	LF	85	75	16	90	64	18	71	49	24
			OATS			OATS			OATS		
3	C-O-W-MxH	None	56	66	12	47	50	18	49	51	28
4	C-O-W-MxH	L	46	61	9	59	53	13	33	59	38
5	C-O-W-MxH	LF	65	63	8	56	55	24	68	61	52
6	C-O-W-MxH	LFM	57	69	14	50	57	29	43	61	52
	Average, Plots 5 and 6		61	66	11	53	56	26	56	61	52
			WHEAT			WHEAT			WHEAT		
7	C W-Al-Al	LF	47	32	4	23	27	16	35	40	26
8	C-W-Al-Al	LFM	46	41	14	21	29	27	40	39	38
	Average, Plots 7 and 8		46	37	9	22	28	22	38	40	32

L=Limestone. F=Fertilizer. M=Manure.

Appendix Table 19.—The Influence of Soil Depth on Wheat Following Oats and on First-year Alfalfa

Plot	Rotation	Treatment	Yield per Acre			Yield per Acre			Yield per Acre		
			Double depth	Normal depth	Subsoil	Double depth	Normal depth	Subsoil	Double depth	Normal depth	Subsoil
			1939			1943			1947		
			WHEAT			WHEAT			WHEAT		
			Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.
1	C-C-W-MxH	None	22	14	2	24	15	6	23	15	9
2	C-C-W-MxH	LF	37	34	3	39	31	7	37	33	11
3	C-O-W-MxH	None	28	22	2	32	22	7	32	21	10
4	C-O-W-MxH	L	25	20	6	22	13	7	26	19	11
5	C-O-W-MxH	LF	35	34	8	42	31	12	44	35	17
6	C-O-W-MxH	LFM	34	35	11	45	36	15	41	34	16
	Average, Plots 5 and 6		35	35	10	44	34	14	42	34	16
			FIRST YEAR ALFALFA			FIRST YEAR ALFALFA			FIRST YEAR ALFALFA		
			T.	T.	T.	T.	T.	T.	T.	T.	T.
7	C-W-Al-Al	LF	3.3	2.0	1.8	3.9	2.6	2.2	1.1	1.0	0.9
8	C-W-Al-Al	LFM	4.1	2.9	2.4	4.5	3.7	3.5	2.2	1.2	1.1
	Average, Plots 7 and 8		3.7	2.5	2.1	4.2	3.2	2.9	1.7	1.1	1 0

L=Limestone. F=Fertilizer. M=Manure.

Appendix Table 20.—The Influence of Soil Depth on Yields of First-year Mixed Hay and Second-year Alfalfa

Plot	Rotation	Treatment	Yield per Acre			Yield per Acre			Yield per Acre		
			Double depth	Normal depth	Subsoil	Double depth	Normal depth	Subsoil	Double depth	Normal depth	Subsoil
			T.	T.	T.	T.	T.	T.	T.	T.	T.
			1940			1944			1948		
			FIRST YEAR MIXED HAY			FIRST YEAR MIXED HAY			FIRST YEAR MIXED HAY		
1	C-C-W-MxH	None	4.5	2.8	1.6	1.9	1.1	0.6	3.6	1.6	0.5
2	C-C-W-MxH	LF	4.8	3.7	2.3	2.9	2.1	1.9	4.7	2.7	2.0
3	C-O-W-MxH	None	4.5	2.8	1.5	2.7	1.3	0.9	3.0	1.1	0.4
4	C-O-W-MxH	L	4.6	3.1	1.3	2.3	1.3	0.8	2.3	1.1	0.7
5	C-O-W-MxH	LF	4.7	3.1	2.2	2.3	1.6	1.6	3.4	2.2	1.8
6	C-O-W-MxH	LFM	4.5	3.6	2.7	2.3	2.0	1.7	3.8	3.0	1.9
	Average, Plots 5 and 6		4.6	3.4	2.5	2.3	1.8	1.6	3.6	2.6	1.8
			SECOND YEAR ALFALFA			SECOND YEAR ALFALFA			SECOND YEAR ALFALFA		
7	C-W-Al-Al	LF	4.8	3.8	3.4	2.8	2.0	1.7	2.3	2.1	1.5
8	C-W-Al-Al	LFM	4.7	4.1	3.6	3.2	2.6	2.2	3.5	2.9	1.7
	Average, Plots 7 and 8		4.8	4.0	3.5	3.0	2.3	2.0	2.9	2.5	1.6

L=Limestone. F=Fertilizer. M=Manure.